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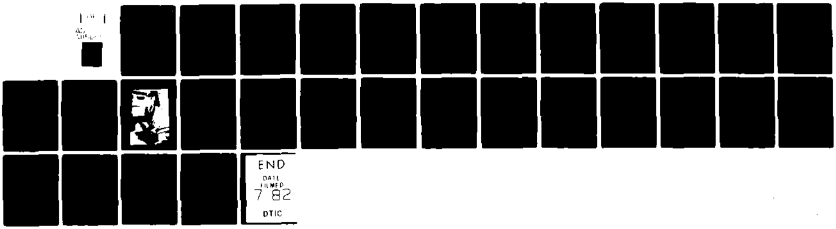

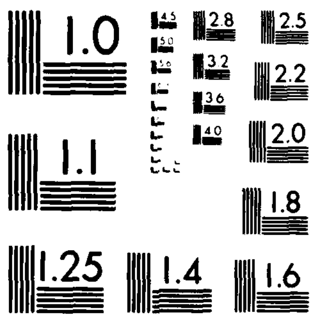

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Technical Memorandum 9-82

A COMPARISON OF DISPLAY FORMATS FOR THE ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM

Frank J. Malkin
Jon J. Fallesen
Harry J. Reed

April 1982
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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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A comparison of two sets of display formats for the Electronic Master Monitor and Advisory Display System (EMMADS) was conducted to determine the effect display format has on performance. Performance measures included accuracy of response and latency of response to a display of a fault, as well as error on a subsidiary tracking task. A subjective questionnaire was used to determine if pilot preferences exist for display format. The results indicated that there were no significant differences in any performance measure due to the display formats but that there was a significant difference in reaction time among the

subsystems. The subsystem with only three alternative faults had a significantly lower reaction time than the two other subsystems with eight and ten alternatives each.

Pilot preference tended to favor those formats which were simple, uncluttered, and which appeared to be least busy.

Conclusions are drawn and suggestions for future evaluations are offered.

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Approved: John D. Weisz
JOHN D. WEISZ
Director
US Army Human Engineering Laboratory

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CONTENTS

A COMPARISON OF DISPLAY FORMATS FOR THE ELECTRONIC MASTER MONITOR AND ADVISORY DISPLAY SYSTEM

INTRODUCTION

Background

In order to avoid enemy detection during combat, US Army helicopters are required to fly nap-of-the-earth (NOE). NOE flight is "flight at varying airspeeds as close to the earth's surface as vegetation, obstacles, and ambient light will permit while generally following the contours of the earth" (1). The attention required of the crew outside the aircraft during NOE flight leaves little time for monitoring the status of critical subsystems such as engine, transmission, electrical, fuel, and hydraulics.

In 1978, the Applied Technology Laboratory (ATL), Ft. Eustis, VA, requested the US Army Human Engineering Laboratory (HEL), Aberdeen Proving Ground, MD, and the Avionics Research and Development Activity (AVRADA), Ft. Monmouth, NJ, to participate in the development of a system that would employ a computer to monitor the status of subsystems for the crew. As a result, a contract was awarded to Sikorsky Aircraft to perform a paper analysis and provide a preliminary design for an Advanced Subsystem Status Monitor that would reduce crew workload during the monitoring of helicopter subsystems (2).

Subsequently, AVRADA assumed responsibility for a follow-on project and a contract was awarded to General Electric (GE) to develop the hardware for an Electronic Master Monitor and Advisory Display System (EMMADS). EMMADS is under development for use in a CH-47 helicopter. The CH-47 was selected because it is considered to be one of the most complex helicopters with respect to subsystem monitoring. It is a twin engine helicopter with two main rotor systems and five transmission gearboxes.

EMMADS employs a computer to monitor the aircraft subsystems and display the status of these subsystems to the crew on a video display unit in the cockpit. It is designed so that the video display unit remains blank except when (a) a fault exists in one of the subsystems in which case the status of the affected subsystem is automatically displayed or (b) a crewmember manually selects one of the subsystems to be displayed.

When fully developed and operational, it is intended that EMMADS will replace all the dials and gauges on the helicopter

instrument panel that are monitored currently by the crew in order to obtain subsystem status information.

It is important that the formats for such a system are designed to transfer subsystem status information to the crew as quickly and as accurately as possible. Prior to this study, the formats proposed by GE had not been evaluated empirically. In order to learn more about the effect of display format on this kind of information transfer, HEL developed a set of display formats for engine, transmission, and hydraulics to be compared with those developed by GE.

Objectives

The objectives of this effort were (a) to compare the HEL developed formats with those of GE by determining through laboratory experimentation if there are significant differences due to display format regarding the speed and accuracy in which critical information on the display screen is sought and identified and performance on a concurrent compensatory tracking task, and (b) to determine, through a structured questionnaire, if a user preference exists for a display format.

METHOD

Subjects

The participants were Army aviators assigned to various activities located at Aberdeen Proving Ground, MD. Twelve participants were tested; however, due to a magnetically damaged computer tape, test data from one subject was lost. Therefore, the results of objective data reported are for 11 participants. Although the aviators were rated in a wide variety of fixed- and rotary-wing aircraft, none were CH-47 rated.

TABLE 1

Aviator Experiential Data for Subjects

Mean age	35
Mean years as rated aviator	10
Mean hours total flight time	2765
Mean hours flight time in multiengine aircraft	779

Apparatus

The apparatus used in this research was a minicomputer, PDP 11/34 (with peripheral devices including a Vector General video display unit, keyboard, control dials, and function switches) and an audio tape recorder. The Vector General video display unit is of a stroke written type with stroke width of 1/120 inch.

Display Functions

Drawings of the GE and HEL display formats used in this study are provided in Figure 1. The actual display size presented to the subjects was 5x7 inches. The seven boxes beneath each display format represent multi-function pushbutton switches. Examples of displays with selected out-of-tolerance conditions or faults are provided in Figure 2. The GE formats were replicated based on drawings in the EMMADS Human Engineering Summary Report (3).

Referring to Figure 1, it can be seen that GE has developed formats for the three subsystems that are considerably different from one another in appearance. Although all the displays incorporate the use of alphanumerics to a degree, either as labels or to provide quantitative information, the only display employing alphanumerics as a format entirely is that for hyraulics. A schematic form of presentation is used for the transmission where the locations of the gearboxes on the display are oriented to their locations in the aircraft. The engine display may be considered graphic in the sense that the vertical "bar graphs" and the pointers on the vertical scales move up and down to indicate the qualitative status of engine parameters. In addition, by alternating the bars and pointers, an attempt is made to provide a visual aid in distinguishing among the four display parameters.

In constrast, the formats developed by HEL are all similar in appearance. An attempt is made to provide a "patterning" effect. When the parameters within a subsystem are operating normally, the pointers on the vertical scales are generally aligned. When an out-of-tolerance condition occurs, the corresponding pointer breaks the pattern by moving up or down on the vertical scale.

GE Displays

In the GE engine display, the magnitude of each parameter is depicted by either a set of moving bars or a set of moving pointers. The left bar or pointer of each set represents the left (no. 1) engine and the right bar or pointer represents the right (no. 2) engine. The quantitative values are depicted in

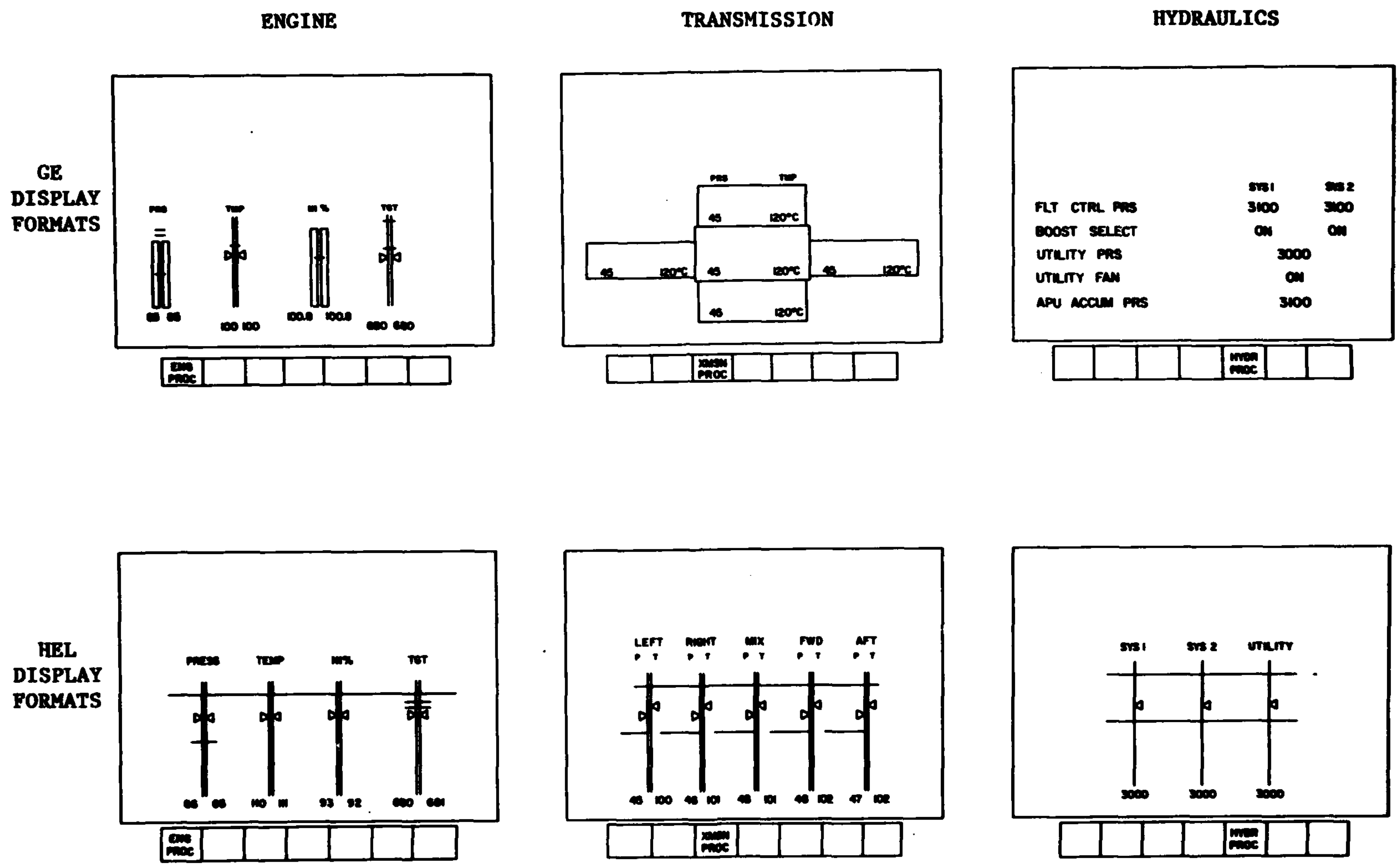


Figure 1. Displays without faults.

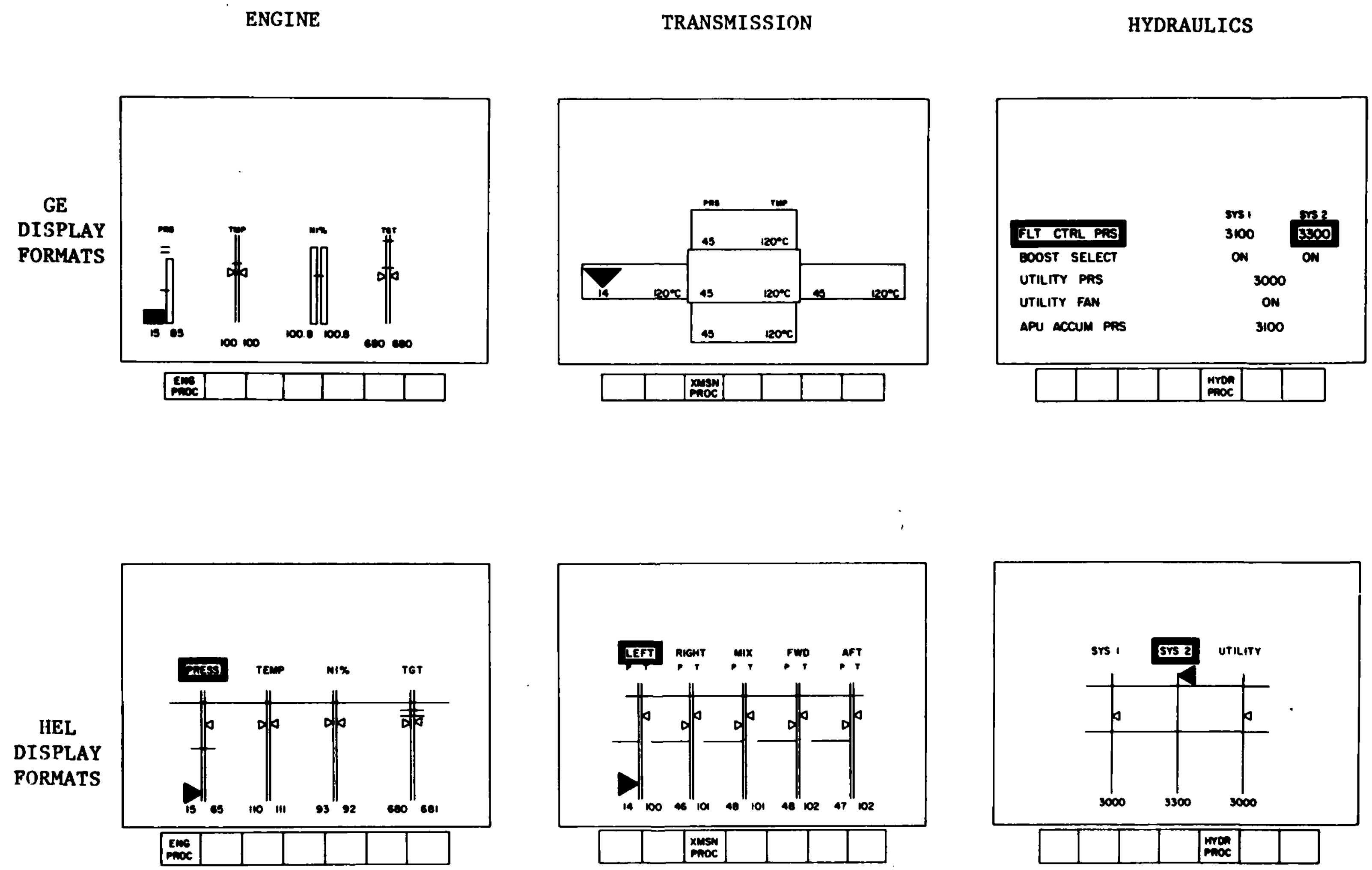


Figure 2. Displays with selected faults.

form at the base of each displayed parameter. As the value of each parameter increases or decreases, the corresponding bar or pointer moves up or down and the quantitative value changes accordingly. When one of the parameters increases or decreases to the point where an upper or lower limit is exceeded, the corresponding bar or pointer enlarges and becomes shaded as shown in Figure 2.

The CH-47 has five transmission gearboxes. They are located at the left engine, the right engine, the forward rotor system, the aft rotor system, and one functions as a combining or mixing transmission. They are presented schematically in the GE display and oriented to their locations in the helicopter with the mixing transmission in the center. The quantitative value for transmission oil pressure and transmission oil temperature is provided within each transmission box. When an upper or lower oil pressure or oil temperature limit has been exceeded, a shaded triangle, with its apex pointing up or down, appears above the quantitative value.

The CH-47 has two hydraulic flight control pressure systems plus a hydraulic utility system. In addition, the status of the boost pumps, utility fan, and accumulator pressure is presented. Faulted parameters in the hydraulic subsystem are highlighted by "boxing-in" the affected parameter as shown in Figure 2.

"Boxing-in" the faulted parameter is used for purposes of this study only. In the GE Human Engineering Summary Report, referenced earlier, faulted parameters in the hydraulic subsystem are highlighted by the use of reverse video. However, the Vector General video display unit used in this study is not capable of reverse video.

GE has since abandoned the use of reverse video and now employs triangular shapes similar to those in the transmission subsystem.

HEL Displays

The left and right pointers on each vertical analog scale in the engine display represent the left and right engines similar to the pointers in the GE display.

The left and right pointers on each vertical scale in the transmission display represent the oil pressure and oil temperature respectively for each transmission.

The single pointers on the vertical scales of the hydraulic display represent the three hydraulic systems of the aircraft.

The pointers in the HEL displays function in the same manner as those in the GE engine display. As the value of each parameter increases or decreases, the corresponding pointer moves up or down on the vertical scale and the quantitative value changes accordingly. When an upper or lower limit is exceeded, the corresponding pointer enlarges and becomes shaded In addition, the parameter label is "boxed-in" (Figure 2).

Procedures

Subjects were familiarized, trained, and tested first with one set of formats (GE or HEL) and then the other. Presentation order was counterbalanced so that six subjects received the GE formats first and six received the HEL formats first. A brief rest period was provided between sets. The total time required for objective testing did not exceed 1 hour.

Familiarization and training was accomplished until subjects were thoroughly familiar with formats and could identify 12 randomized faults without error. Sufficient practice trials were conducted to insure that subjects were familiar with the test procedures. Subjects were instructed to identify subsystem faults as quickly and accurately as possible.

Subjects were seated so that the line of sight distance to the Vector General video display unit was 28 inches (Figure 3). The subjects used a one axis control dial to perform a compensatory tracking task which required maintaining an aircraft symbol (Figure 4) in the "wings level" position between three pointers fixed on the display. The tracking task was located in the upper portion of the video display. At random time intervals, between 2 and 6 seconds, during the performance of this tracking task, a subsystem fault was presented on an area of the screen just below the displayed tracking task. The faulted subsystem remained displayed until the subjects responded by depressing the space bar on the keyboard. The subject then verbally identified the fault, which was recorded by tape recorder and by an experimenter. Fault identification required qualitative information only; for example, "left transmission oil pressure low." Upon completion of the response, an experimenter activated a function switch which permitted the computer to control the presentation of the next fault.

Upon completion of all test trials, subjects completed a structured questionnaire in which they indicated their preference for a given format by circling an appropriate descriptor phrase in a bipolar rating scale and described the characteristics they liked or disliked about each format. Two sets of questionnaires were used so that the first set of display formats presented to the subject was referred to as set "A," and

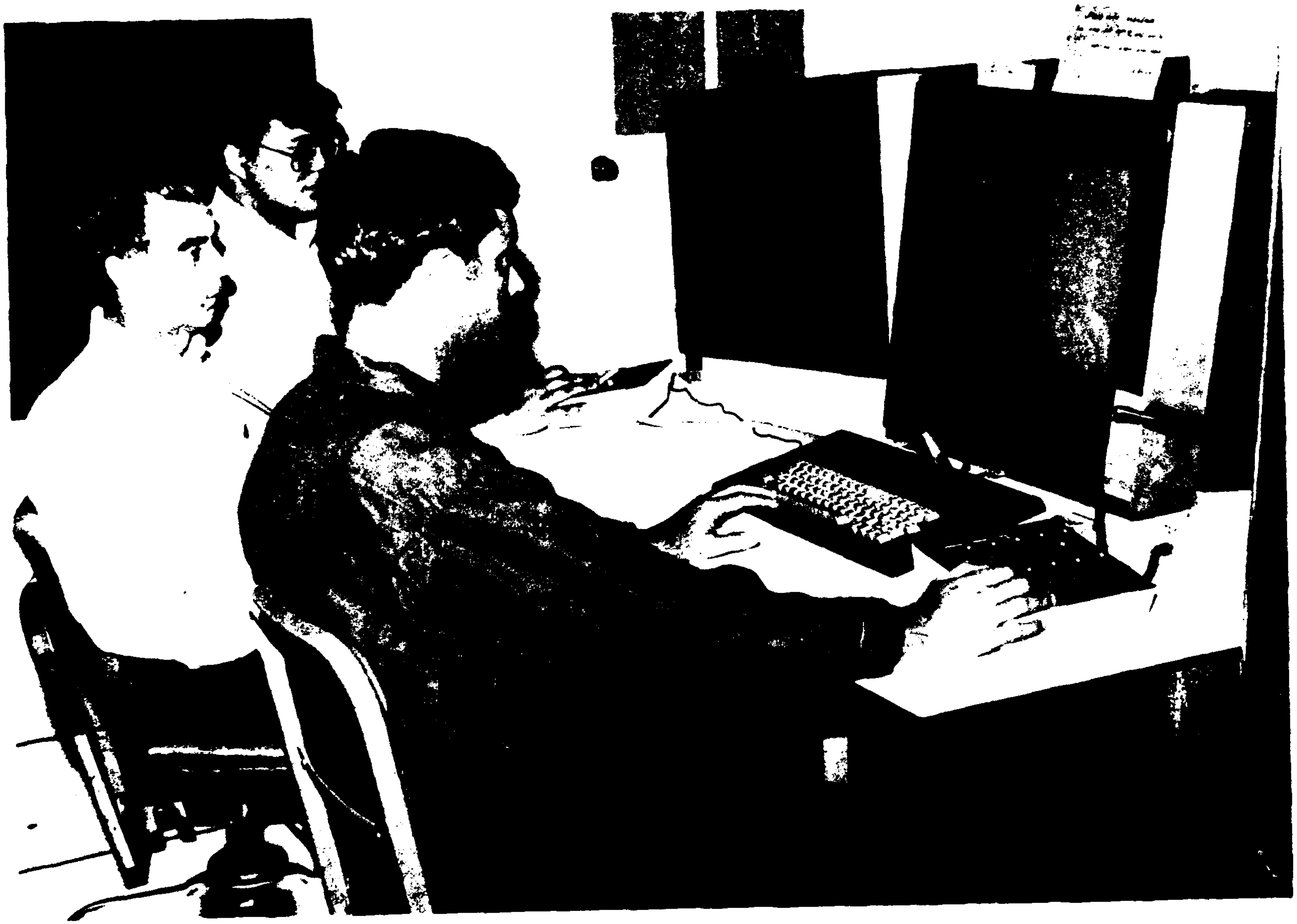


Figure 3. Experimental station.

the second, as set "B." A sample of the questionnaire is provided in the appendix.

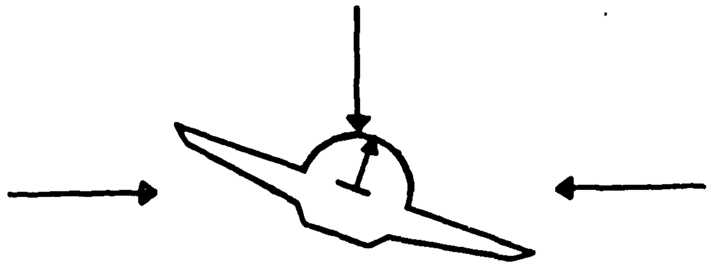


Figure 4. Tracking task display.

Design

A 2 x 3 (format x subsystem) factorial design with repeated measures on subjects and trials was used (Figure 5). The number of trials varied according to subsystem. Each of the subsystems contained a different number of possible fault trials. Six trials were presented for the hydraulic subsystem, eight for the engine, and ten for the transmission. The presentation order of subsystems and faults was randomized. Each subject received a total of 48 trials (24 for the GE set and 24 for the HEL set). Twelve subjects were individually tested.

	D1			D2		
	SS_1	SS_2	SS_3	SS_1	SS_2	SS_3
	$T_1, T_2, \ldots T_6$	$T_1, T_2, \ldots T_8$	$T_1, T_2, \ldots T_{10}$	$T_1, T_2, \ldots T_6$	$T_1, T_2, \ldots T_8$	$T_1, T_2, \ldots T_{10}$
S_1						
S_2						
⋮						
S_{12}						

Figure 5. Experimental design.

D_1 = GE set of formats
D_2 = HEL set of formats
SS_1 = Hyrdraulic Subsystem
SS_2 = Engine Subsystem
SS_3 = Transmission Subsystem
T_1, T_2, ... T_{10} = Trials
S_1, S_2, ... S_{12} = Subjects

The dependent variables consisted of (a) accuracy of fault recognition, (b) reaction time, and (c) tracking error root mean square (RMS).

Accuracy of fault recognition was recorded by the experimenter and by tape recorder. Reaction time was recorded by the computer as the elapsed time from the onset of the faulted subsystem to the activation of the keyboard spacebar by the subject. The reaction time was a function of attention to the tracking task and involved the process of perceiving, identifying, and responding to the displayed fault. Tracking error RMS (5) was computed and recorded by the computer.

RESULTS

Objective Data

The calculated means and standard deviations for the dependent measures of reaction time, accuracy, and tracking error RMS for display formats and type subsystems are provided in Table 2.

To conduct statistical comparisons, means were taken across trials within each subsystem and display format for each subject. Thus, the statistical analyses procedures were performed on 66 total observations for each dependent measure (2x3x11).

Because there is no subject variance in accuracy in the hydraulic subsystems and very little in the engine and transmission subsystems, the dependent measure of accuracy was dropped from the multivariate analysis of variance (MANOVA) design.

A univariate analysis of variance was performed on accuracy whereby a reduced design eliminated the hydraulic level of subsystem. The results indicated that there were no significant differences at the .95 level of confidence. There was no main effect for display format, $\underline{F}$ (1,10)=.051; no main effect for subsystem, $\underline{F}$ (1,10)=1.34; and no interaction between display format and subsystem; $\underline{F}$ (1,10)=.461.

The results of the MANOVA (4) performed on the dependant measures of reaction time and tracking error RMS are shown in Table 3. The hypothesis and error matrices for each source are given in the column headed "Sums of Squares and Cross Products Matrix." "Pillais Trace" is the computed test statistic using the two matrices. The statistic is based on the greatest-characteristic root distribution with parameters S, M, and N. An F statistic can be approximated from Pillais Trace and the distribution parameters, and a significance level can be associated with each F value. A significant main effect in the performance vector is indicated in the subsystem factor. Inspection of the mean vectors for engine and transmission indicate that the engine displays have shorter reaction times and

TABLE 2

Means Across Subjects

	Display Formats					
	GE			HEL		
	Reaction Time (S)	RMS (rad)	Accuracy (percent)	Reaction Time (S)	RMS (rad)	Accuracy (percent)
ENG	1.64	.88	98	1.75	.95	99
	(.49)*	(.19)	(.05)	(.60)	(.22)	(.04)
XMSN	1.73	.96	96	1.86	.98	95
	(.63)	(.16)	(.05)	(.66)	(.17)	(.12)
HYD	1.50	.95	100	1.30	.92	100
	(.38)	(.17)	(0)	(.40)	(.19)	(0)

* Standard Deviation

TABLE 3

Multivariate Analysis Source Table

Source	Sums of Squares and Cross Products Matrix		Pillai's Trace	S, M, N	Approx F	Significance
Display	.002*		.033	1, 0, 7/2	.153	.861
	.004**	.007***				
Subject X Display	3.904					
	-.054	.227				
Subsystem	1.837		.684	2, -1/2, 17/2	5.193	.002
	.113	.035				
Subject X Subsystem	1.062					
	-.226	.909				
Display X Subsystem	.383		.344	2, -1/2, 17/2	2.078	.102
	.099	.033				
Subject X Display X Subsystem	.925					
	-.055	.490				
Subject	11.460					
	-.774	.437				

*Sums of Squares for reaction time (RT)
**Cross Products for RT-RMS
***Sums of Squares for RMS

less tracking error RMS than did the transmission displays, (1.70/.92) and (1.80/.97), respectively.

Ninety-nine percent simultaneous confidence intervals were placed on pairwise differences in order to conduct multiple comparisons of subsystems (Table 4). The intervals for the reaction time indicate that the engine and transmission subsystems did not significantly differ but the hydraulic subsystem was significantly different from both the engine and transmission subsystems. The 99 percent simultaneous confidence intervals on subsystem indicated that there were no differences for tracking error.

TABLE 4

99 Percent Simultaneous Confidence Intervals for Mean Subsystem Differences

Subsystem	Reaction Time		RMS	
Difference	Lower Bound	Upper Bound	Lower Bound	Upper Bound
ENG-XMSN	-.3926	.1926	-.3257	.2157
ENG-HYD	.0024	.5876	-.2907	.2507
XMSN-HYD	.1024	.6876	-.2357	.3057

Therefore, it is concluded that the significant main effect in the MANOVA is primarily due to the short reaction times for the hydraulic subsystem (Figure 6).

Subjective Data

The results of the subjective questionnaire are provided in Tables 5 through 7. Frequency of preferences and summary of comments are provided for display formats by subsystems.

DISCUSSION

The results indicate that there are no significant differences regarding reaction time, response accuracy, or tracking performance due to the display formats tested.

The results did show a significantly lower mean reaction time for the hydraulic subsystems when compared with the engine

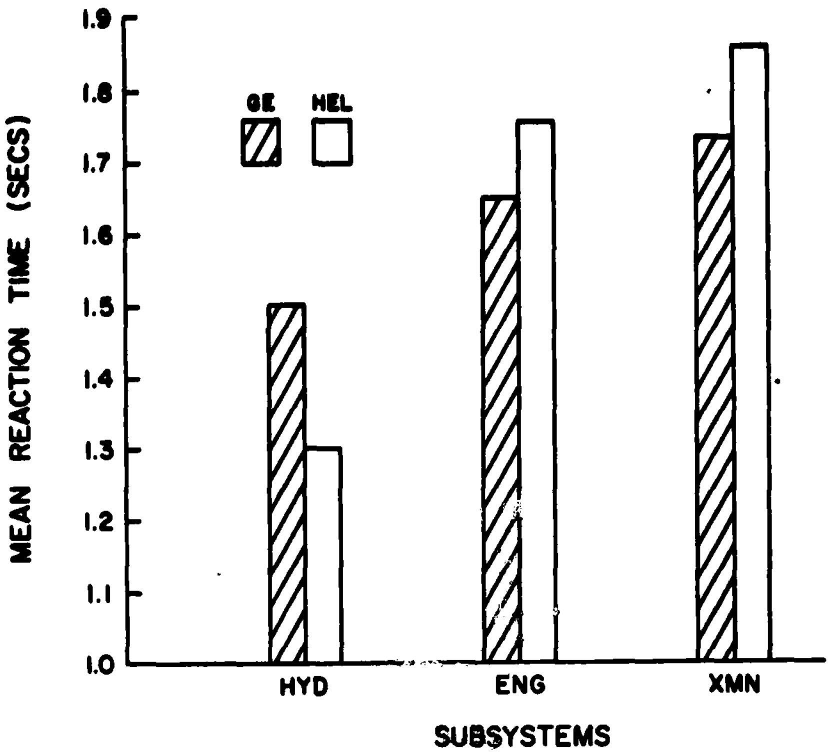


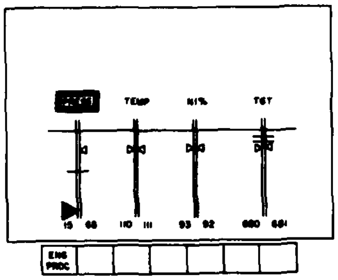
Figure 6. Mean reaction times for subsystems.

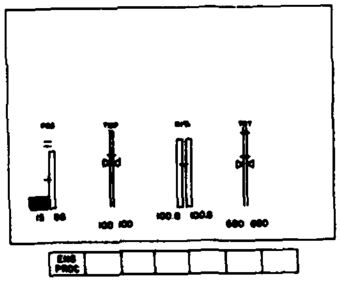
and transmission subsystems (Figure 6). This is not totally surprising considering that the hydraulic subsystem has only three parameters from which to identify potential faults while the engine has eight and the transmission has ten. Reaction time increased with increases in information, or more exactly in the present case, the number of possible faults for each subsystem. Thus, the hydraulic system which has only three alternatives to choose from had a significantly lower reaction time or processing time.

During the test trials the experimenter observed that some subjects experienced a degree of confusion between the HEL engine and transmission display formats. This confusion was expressed as a hesitant or halting verbal identification of the presented fault. During the debriefing, the affected pilots agreed that there was some confusion between the displays and that it was due to the similarity of the formats and the fact that, in the engine display, pointers under each parameter represent left and right engines, and in transmission display, the pointers represented oil pressure and temperature.

TABLE 5

Summary of Subject Preferences and Comments for the Engine Display





Frequency of Pref: A B

High Preference For A	Preference For A	Slight Preference For A	No Preference	Slight Preference For B	Preference For B	High Preference For B
5	1	2			1	3

Summary of Comments:

Preference for A:

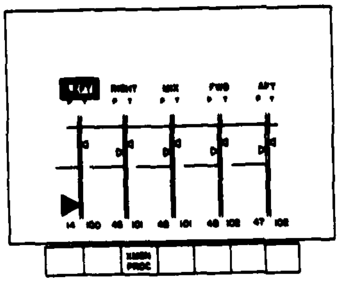
1. All pointers were easier to interpret.
2. Liked horizontal line indicating upper limit.
3. Boxing-in faulted parameter was helpful.
4. Display B too busy, too cluttered, too many horizontal lines, difficult to interpret bars.
5. Prefer either all pointers or all bars.
6. Alternating bars and pointers were not helpful cues.

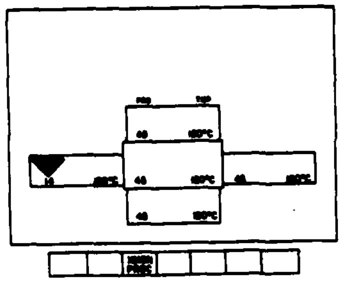
Preference for B:

1. Those who preferred display B stated that alternating bars and pointers were helpful cues.

TABLE 6

Summary of Subject Preferences and Comments for the Transmission Display





Frequency of Pref: A B

High Preference For A	Preference For A	Slight Preference For A	No Preference	Slight Preference For B	Preference For B	High Preference For B
2	1		1	1		7

Summary of Comments:

Preference for A:

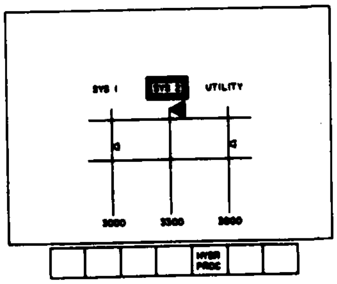
1. Liked having each gear box labeled and not having to identify gear box by position.
2. Display B does not provide upper and lower limits.
3. Looking under labeled transmission to see if pointer is high or low easier than schematic.

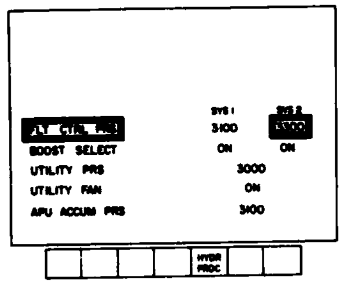
Preference for B:

1. Schematic orientation of gearboxes to relative position in helicopter helpful.
2. Display A is too busy; too many pointers on display.
3. Would be helpful if PRS and TMP labeled on left and right gear boxes in display B.

TABLE 7

Summary of Subject Preferences and Comments for the Hydraulic Display





Frequency of Pref: A B

High Preference For A	Preference For A	Slight Preference For A	No Preference	Slight Preference For B	Preference For B	High Preference For B
8	2	1				1

Summary of Comments:

Preference for A:

1. Relative position of pointer interpreted quicker than digital readout alone.
2. Upper and lower limit lines provide helpful cues.
3. Display B contains too much information; has cluttered appearance.

Preference for B:

1. Displays more information and is easier to use.

The participants were enthusiastic about the EMMADS concept as a method of reducing workload in the cockpit. However, several pilots cautioned that if air crews are to have confidence in such a system, it is absolutely essential that it be reliable and have built-in redundancy.

Pilot preferences tended to favor those formats which were simple, uncluttered, and which appeared least busy as exemplified by the frequency of preference for the HEL hydraulic display format.

CONCLUSIONS AND RECOMMENDATIONS

There were no significant differences between the HEL and GE developed display formats regarding the speed and accuracy in which critical information on the display screen is sought and identified or in performance on a concurrent tracking task.

There was a significant difference in reaction time for the hydraulic subsystems when compared with the engine and transmission subsystems. This result reinforces the notion that reaction time can be explained in terms of information processing in that the hydraulic subsystem has only three alternatives to choose from and the engine and transmission have eight and ten respectively.

The original Subsystem Status Monitor report by Sikorsky Aircraft recommended a caution/warning panel in addition to the main display that would be located at the top of the instrument panel just below the glareshield. The caution/warning panel would incorporate an alphanumeric "one liner" such as "ENG 1 OIL PRESS LOW." Future studies could investigate the effect of this type of approach on information processing time.

The confusion that was experienced by some of the subjects due to the pointers in similar appearing display formats, representing different types of information, is an area that deserves consideration when designing formats for subsystems that will appear successively on a video display unit with formats of other subsystems.

In terms of pilot preferences, display formats should be designed so that they are simple and uncluttered in appearance.

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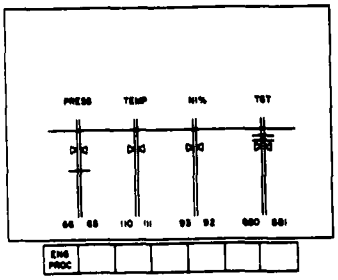
APPENDIX

EMMADS QUESTIONNAIRE

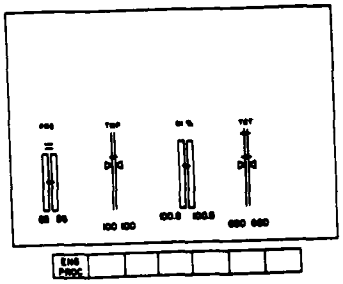
EMMADS QUESTIONNAIRE

For each of the following subsystems, please indicate your preference for display format by circling the appropriate descriptor phrase.

1. <u>ENGINE</u>



A



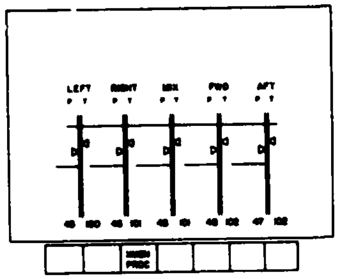
B

High Prefer- ence For A	Preference For A	Slight Prefer- ence For A	No Prefer- ence	Slight Prefer- ence For B	Preference For B	High Prefer- ence For B

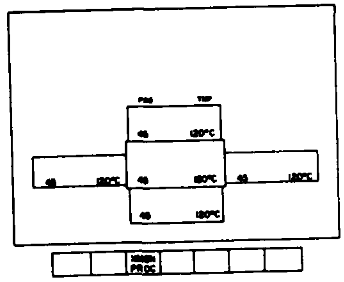
Please describe the display characteristics that you liked or disliked about each engine format:

EMMADS QUESTIONNAIRE (cont'd)

2. TRANSMISSION



A



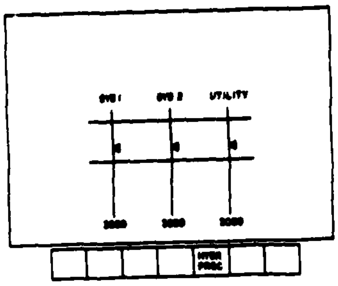
B

High Prefer- ence For A	Preference For A	Slight Prefer- ence For A	No Prefer- ence	Slight Prefer- ence For B	Preference For B	High Prefer- ence For B

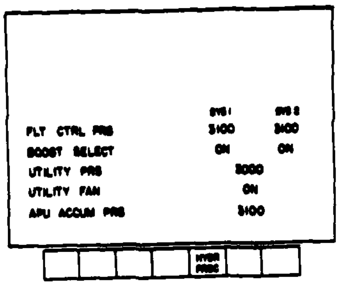
Please describe the display characteristics that you liked or disliked about each transmission format:

EMMADS QUESTIONNAIRE (cont'd)

3. **HYDRAULICS**



A



B

High Preference For A	Preference For A	Slight Preference For A	No Preference	Slight Preference For B	Preference For B	High Preference For B

Please describe the display characteristics that you liked or disliked about each hydraulic format:

DATE
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